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Command and Control Systems Requirements Analysis

Volume 3
C2 System Functions in the Hierarchy of Objectives

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ADMINISTRATIVE INFORMATION

The work reported herein was conducted for the Deputy Chief of Naval Operations (Naval Warfare) during FY 90 as part of the Naval Warfare Analysis Program. This document presents the results of a collaborative effort involving SAIC and NOSC Code 171 Systems Analaysis Group, personnel.

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COMMAND AND CONTROL

SYSTEMS REQUIREMENTS ANALYSIS

VOLUME 3

COMMAND AND CONTROL SYSTEM FUNCTIONS

IN THE HIERARCHY OF OBJECTIVES

SEPTEMBER 1990

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SECTION 1.0 INTRODUCTION

Military and Naval Operations are a complex set of activities involving organizations of people and equipment in conflict with another such organization. Analysis of the overall effectiveness of the opposing forces is a difficult task. Part of the problem is the enormous complexity of the interaction. Another difficulty is the lack of means to evaluate the contribution of Command and Control (C2)* to the eventual outcome.

Descriptions of large scale complex systems are very difficult to derive because of the many levels and frames of reference required for understanding. These many levels are necessary because of the nature of the problem and because we are limited in our ability to comprehend more than a few aspects of a problem at the same time. The concepts being presented here will not make the problem simple, but some simple tools will be provided, which, when applied consistently, can be used to gain insight into the problem and, when applied repetitively, iteratively, or recursively, can be used to describe a complex system in more manageable terms. These insights are based on common sense and well-known ideas, but this presentation provides a framework of conventions to clarify relationships and identify similarities and differences among a few fundamental concepts about the nature of systems. The role of decision making in systems is also stated in a way that can be applied to all aspects of the problem.

1.1 BACKGROUND

Naval Warfare needs are described in a series of Top Level Warfare Requirements (TLWRs) documents. TLWRs have been developed by the Office of the Chief of Naval Operations (OPNAV) for some Warfare Mission Areas (WMA), as well as for Electronic Warfare (EW) and for the Carrier Battle Force (CVBF). TLWRs are now being addressed at an even higher level, that of the Functions of the Navy, beginning with Sea Control and, subsequently, for Power Projection.

The TLWRs for Sea Control are expressed in terms of Mission Success Criteria (MSCs). These are statements of objectives to be achieved in various mission situations. The ability to achieve the MSCs is expressed as a combination of Required Capabilities (RCs) in the various WMAs. The RCs are, in effect, sub-objectives that would lead to the accomplishment of the MSCs. In the TLWRs for WMAs, these RCs become MSCs and, to support them, there is a set of RCs for platform mobility and sensor and weapon systems. C3I requirements have been stated subjectively in qualitative and quantitative terms in the TLWRs and other references, but not in a way that exhibits the contribution of C3I to Warfare goals.

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* For the purposes of this report, the acronyms C2, C3, and C3I will generally refer to the processes of Command and Control (C2); Command, Control, and Communications (C3); and Command, Control, Communications, and Intelligence (C3I); while the word "systems" will be appended if necessary to distinguish physical resources from the processes. C2 involves decision making and the total information processing that supports it. C3 adds the information exchange process among decision-making elements. C3I represents an emphasis on processing and exchange of Intelligence data within the C3 process, not on the collection of Intelligence data. Similarly, the Surveillance data collection is not included within every C2 process, unless it is the Mission of that element.

Within the organization of the Deputy Chief of Naval Operations for Naval Warfare, the Director, EW, C3I, and Space Warfare (OP-76) is responsible for the C3I Warfare Support Area Appraisal, a major component of the Navy's Planning, Programming, and Budgeting System. OP-76 is also responsible for the administration of Team "C", which is guiding the development of the Navy's Battle Management C3I Master Plan. OP-76 is evolving a methodology for analyzing C3I Warfare requirements in support of these efforts. Previous work has resulted in a C3I Operational Requirements Framework (reference (g)), hereafter referred to as the Framework, and the conduct of Workshops on Tactical C3I Requirements and Deficiencies for Power Projection and Sea Control. This task is intended to extend and enhance the Framework in support of the next cycle of assessment and master plan development.

Within the Space and Naval Warfare Systems Command, the Warfare Systems Architecture and Engineering (WSA&E) Directorate (SPAWAR-30) directs the development of architectural descriptions and assessments of current and future Naval Warfare Systems. The process is governed by the issuance of the TLWRs by OP-07. In response, the Architecture team is attempting to devise a means of providing a traceable accounting of the relationship between system performance and the TLWR. This has given rise to the development of a methodology for Architectural description, modeling, and assessment that is ongoing. This methodology addresses Operational Functions, System Capabilities, and Force Performance Measures. The Warfare Mission Support Areas Division (SPAWAR-312) has solicited the Naval Ocean Systems Center (NAVOCEANSYSCEN) to lead a team of Navy Laboratories to address C3I Architecture issues. This report provides support and guidance in coordination with that effort.

The first objective was to develop a hierarchical multi-level analysis structure of functions and metrics, down to the Force level, that relates Operational Functions and Resource Capabilities to Mission Success Criteria, Required Capabilities, and Force Performance Measures, and describes how these depend on Mission context. The analysis structure makes evident the contribution of C3I, embedded in the operation, to effect Mission Success. The first volume of this Technical Document, subtitled The Hierarchy of Objectives Approach (reference (c)), addresses an approach to functional analysis of Naval Warfare at the top levels, addressing military objectives and mission area characteristics to the intra-task force level, with a focus on how C2 affects results. The second volume, subtitled Measuring C2 Effectiveness with Decision Probability (reference (d)), presents methods for mathematically relating capabilities and objectives at those levels. This metric analysis is based on a common measure (conditional probability) to quantify the effect of dependency among functions at all levels of the hierarchy. The probability of making a decision affects what activities will take place, which, in turn determine what outcomes will occur.

This volume (vol. 3) focuses on functional and metric analysis at the system level, in particular, for C3I systems. System Functions support Operational Functions, including Command Process Functions, and are supported by Equipment Functions. Equipment Functions are also addressed.

1.2 OVERVIEW OF APPROACH

1.2.1 Role of Hierarchy of Objectives

A Hierarchy of Objectives can be stated in terms of Missions, Functions, and Tasks. For a particular Force or System, its Functions are the activities it performs in order to accomplish its Mission. Its Tasks are its subfunctions, which are performed by its parts or subsystems. Mission objectives are based on achieving a preferred set of outcomes, which are particular states of the enemy's forces and ones' own, as well as the state of the environment, e.g., occupied territory. These objectives may support a higher objective, such as the capitulation of the enemy. The strategies, operations, tactics, and procedures used by each Force are a hierarchy of functions or processes that correspond with their hierarchy of objectives. The sub-objectives are to achieve

favorable outcomes of the functions, i.e., those outcomes that contribute to achievement of the outcomes stated in the Mission objectives. Functions/objectives at each level may support several of those at a higher level or of a larger Force. The role of the Hierarchy of Objectives is to define the set of functions and their favorable and adverse outcomes, not only at the highest level, where the TLWRs establish Mission Success Criteria, but also for Required Capabilities and below. The sets of outcomes form the basis for defining a measure of potential achievement of the objectives.

An exemplary list of Missions, Functions and Tasks based on the Hierarchy of Objectives is provided in Appendix A. Navy Functions, such as Sea Control and Power Projection, are supported by Primary Warfare Tasks or Warfare Mission Areas, e.g., Anti-Submarine Warfare (ASW) and Amphibious Warfare (AMW), which are, in turn, supported by Warfare Support Tasks or Support Mission Areas, including Surveillance, Intelligence, Electronic Warfare, and Command, Control, and Communications. The Hierarchy of Objectives identifies mutually supportive purposes as a network of functions such as alerting associated forces and countering enemy forces, which integrate the roles of the Mission Areas.

1.2.2 Role of Decision Making in the Hierarchy of Objectives

Decision making is a function that is performed at all levels of the Hierarchy of Objectives. It is the function that determines which objectives to pursue, which functions to perform and which resources to use and when. The purpose of decision making is, therefore, to allocate resources to perform functions in support of higher objectives. The decision process consists of the performance of decision functions that involve interpreting information or choosing courses of action. These functions, called Command Functions, have decisions as their outcomes. They are described in detail in Appendix A of reference (c), which provides an updated version of the Command Process Model (reference (a)) previously used in OP-76 assessments. Reference (b) is a stand-alone version of Appendix A of reference (c).

The Command Process Model (CPM) describes the information functions of Plan, Observe, Assess, and Execute as the principal decision functions. In addition, the Sense and Act functions provide the coupling with the physical states of the system and the environment. Communications functions provide the connectivity between information functions, internally and externally. These CPM functions are summarized in Appendix A of this volume, as well.

1.2.3 Elements of System Description

A method of describing systems of all magnitudes was defined in reference (c) and is summarized in reference (d). The approach is similar to techniques in object-oriented programming. Objects are described by their states or attributes and by functions that are relationships between the states. Going beyond the basic ideas of object-oriented programming, this method recognizes that functions represent a causal conditioning between the states, i.e., that the value of a state (outcome of the function) depends on the values of other states. This conditioning can be the basis of a graphic technique for depicting architectural structure. The Hierarchy of Objectives is such a structure of functions to be performed in order to achieve preferred values of states. The conditioning relationship also provides a foundation for assigning a measure of likelihood to the values of a state that is dependent on the values of the other states. This can be a deterministic or stochastic likelihood that can be expressed as conditional probability or related measures.

1.2.4 Probability as a Common Measure

Probability is a term that may mean randomness or proportionality or tendency. Mathematically, it is simply a measure whose value is in the range, 0 to 1. In addition, the total probability must add to 1.0 over the mutually exclusive and exhaustive domain on which it is defined. Any of the other meanings can apply, subjectively, depending on the context of the problem. The simple idea of defining the "probability of achieving outcomes" as a common measure is a very natural one. It is also very useful and necessary to have this standard criterion at each level of description of the objectives and processes under consideration. This approach makes probability a common denominator to relate other measures of goodness (attributes and "-ilities"), along with the other universal variable, time. Probability is a non-dimensional measure, but it is referenced to the dimensions of the attributes or states that characterize outcomes.

Due to recent results in Conditional Probability and system analysis techniques, this approach will provide the means to understand the relationship between system performance and Mission Success Criteria. The probability measure is not an isolated quantity. It is a surrogate for related criteria and capabilities. The measure is a conditional probability, where the dependencies of various outcomes of functions on those of other functions is reflected in the conditioning of the probability measure. The capabilities are statements of desired outcomes conditioned on the context of the requirement statement. After translating those capabilities into probability space, the Hierarchy of Objectives provides a roadmap for mathematically combining the probabilities of the lower levels to produce a probability of the outcomes at the highest level, where the ultimate measure is the "probability of achieving preferred outcomes". For example, the probability of destroying more than x% of the enemy, while retaining more than y% of own forces is a joint probability of the mutual attrition outcome.

1.2.5 Decision Probability as a Measure of C2 Effects

Probability is also used to relate the effects of C2 to the accomplishment of the Mission. Since decisions are the outcomes of the Command Process, the measure of the contribution of decision making is the probability of making particular decisions. The functions actuated by decisions are conditioned, in part, on the making of those decisions and the decisions are conditioned on the outcomes of the decision subfunctions and the information available. The effect of making a particular decision or another or of its timeliness is reflected in the resulting probability of achieving the top level objective, all other conditions and probabilities being kept the same. The following probability statements are examples of operational C3I requirements:

> Pr(Data Obtained | communications connectivity, status of resources),
> Pr(Accurate Picture | Data Obtained, Accuracy of data, time delay, expectations),
> Pr(Recognize Situation | Accuracy of Picture, expectations),
> Pr(COA/resource selected | Plan in place, situation as recognized, authority to act), and
> Pr(Decision promulgated | COA,communications connectivity, etc.).

(The symbols Pr(X | Y) mean the probability that X is accomplished (outcome) given Y has happened (conditioning).) These are conditioned on the plan that is in effect and how well it anticipated situations (expectations) and provided guidance for dealing with them (contingency plans). This suggests some requirements for planning:

> Pr(Plan selected, in place | lead time), and
> Pr(Need to Replan | Plan in place, situation as recognized, Intelligence, etc.).

The above probabilities can be seen to relate to the elements of the Command Process Model, since the outcomes are the results of Plan, Observe, Assess, and Execute processes.

The time to accomplish these functions is inherently included in these requirements, often in terms of "timeliness". Component times may involve:

- Time to obtain data,
- Time to generate picture,
- Time to recognize situation or need to replan,
- Time to decide on course of action and resource allocation,
- Time to promulgate decision, and
- Time to replan.

With these types of C3I measures in place, along with Mission-oriented requirements measures, the overall outcome can be assessed with a view into the contribution of C3I, since the activation of Warfare Mission Area functions is conditioned on the direction to carry them out. The time to carry them out will not begin until they are initiated. Therefore, the achievement of the objectives depends on the probability of activation and the time to initiate action. This is explicitly the connection between C2 performance and the completion of Mission objectives.

1.2.6 Classes of Functions

The primary ingredient in describing a system is understanding its purpose. The primary or ultimate purpose is its Operational Function. There is a lot of necessary or unavoidable activity in a system which may also be called functions. These may not be considered the primary purpose of the system, but they are functions. It is useful to describe several classes of functions: Operational Functions, System Functions, and Equipment Functions.

Operational Functions are derived from the Mission that the system is supporting. System Functions are tools that assist in the accomplishment of the Operational Functions. These are the subject of this document and will be elaborated in detail. Equipment Functions provide the means to accomplish the System Functions.

The role of the decision function was discussed in the Hierarchy of Objectives. Since decisions enable all other functions, there are varieties of decision functions in all the classes of functions. The Command Process Model addressed decision functions as Operational Functions. This document will describe the C3 System and Equipment Functions that support the Command Process Functions. C3I System and Equipment Requirements must be based on the ability to perform the System and Equipment Functions and related to the probability of making decisions.

1.3 ORGANIZATION OF REPORT

Having presented an overview of the approach taken in these studies, an expansion of these ideas is included in section 2.0. This lays the groundwork for the presentation of a method for defining System Functions and Equipment Functions in section 3.0. A discussion of some ideas and issues about the way C3 systems are designed are provided in section 4.0. The factors that need to be considered in assessing C3 systems are discussed in section 5.0. Section 6.0 presents references.

SECTION 2.0 C3 SYSTEM ANALYSIS METHODOLOGY

The overall Naval Force is a very complex system and tracing the impact of alternative systems is very difficult. Operational relevance is best understood in terms of operational objectives while system tradeoffs are often performed as a function of system parameter changes. In addition to the effects of changes in physical parameters, performance should also be understood in terms of the effects of coordination. Changes of procedures and force multiplier effects are just as important in assessing overlaps and shortfalls as are equipment changes.

The relevance of C3 systems is derived from the Mission objectives and the situation, as well as the organization they are intended to support. C3 systems consist of computer and communications networks whose characteristics are determined by hardware components and software algorithms. The analysis methodology must, therefore, be applicable, primarily, to the large scale system but also provide the ability to zoom into, focus on, and trace upward from all levels of decomposition.

In spite of the complexity, the system description must be understandable. This document is intended to provide a means to describe system functionality and data in order to identify similarity and differences among systems and to identify alternative ways of structuring the system. Some examples of the types of issues that might arise from such an analysis are provided in section 4.0 to demonstrate the ideas. To achieve this, the method should use uniform terminology from level to level and use standard, repeatable patterns of description to underscore the similarities of systems, whenever possible. This will provide for consistency where appropriate but will also highlight differences when they are significant. Too often, system descriptions appear to show differences where there are none, because the terminology and symbology that were used were different, not because there were substantive differences. In addition, the use of repeatable patterns and modularity can help capture the complexity of the system yet be simple in nature so that it is understandable.

This simplicity and commonality also helps in assessing alternatives by making the description more easily modifiable and provides traceability of the impact of changes on overall performance. Other requirements for traceability are to identify quantifiable and measurable attributes or parameters at all levels and to formulate meaningful mathematical interdependencies between these parameters and performance measures at a coarser or finer level of description.

2.1 ASPECTS OF SYSTEM ANALYSIS

The major aspects of system analysis are Goals, States, Functions, Resources, and Organization. There could be multiple dimensions within each of these areas.

To maintain the operational relevance and traceability of operational performance, decomposition should proceed with the perspective of Goals and Objectives as an orientation. Goal decomposition is directly related to State and Function decomposition. This defines the range of States and necessary Functions to be performed, in particular, Operational Functions. Operational Functions are derived from operational doctrine and tactics. At each level of decomposition, the Organizational element and the associated Resources that perform the Operational Functions are identified. Of course, these must be subsets of the Organizational element and Resources that are applicable at the next higher level of decomposition. The Goals also form the basis of the effectiveness measures of the functions of the system.

As Functions are decomposed, the performance goals of the subfunctions must contribute to the performance goal(s) of the higher function. (See reference (d) for a discussion of the interdependence of performance measures of functions and subfunctions.) This relationship may be revealed by examining the operating sequences of the subfunctions. This is sometimes called an operational procedure, or tactic, which defines the relationship of subfunctions to functions. It also provides the traceability of subgoals to goals. In order to understand the effect of coordination, the interaction between organizational elements must be described. This is partially defined by, or may be the purpose for, the procedures. This organizational relationship is further dependent on, or could be the basis for, the physical arrangement and connectivity of the Resources. Again, performance will be affected by resource connectivity, as well as by organizational interaction and functional procedures.

In summary, the approach consists of the decomposition of Goals, States, Functions, Resources, and Organization, and the description of the structure provided by the operational procedures, organizational interactions, and communications connectivity in order to trace performance. This might be described as a process of decomposition, structural description, and performance tracing.

2.1.1 Goals

As discussed earlier, Goals are the performance objectives (metrics of success) associated with the achievement of a Function and procedures are the relationships between the subfunctions. Procedures consequently provide the basis for relating subgoal performance to goal performance.

Since there are several kinds of Functions (Operational, System, and Equipment), it may be generally true that there are Operational Goals, System Goals, and Equipment Goals, but, unless otherwise stated, Goals will be considered Operational Goals or Objectives.

It is important to remember that Goals are stated in terms of some operational problem. The measure of success will be different for different situations. This is another way of saying that Goals are context dependent. The Operational Goals will depend primarily on the particular Mission, phase of operation, and region of interest. Furthermore, not all functions can be performed at all times at Goal levels of "full speed." The importance of a particular Function will determine the priority for allocation of resources to its accomplishment. This implies variation in the target level of performance of other Functions.

2.1.2 Defining States, Functions, and Data

Systems are describable in terms of their functions and their influences on one another. In general, States produced by one set of functions are the influences that effect States produced by other functions. In an information processing system, data are the information states that pass between functions. For purposes of this report, a <u>system function</u> is a process that takes one or more forms of data and produces another set of data. These functions may be performed by operators or machines or, interactively, by both.

Functions may be decomposed into subfunctions. There is an equivalent decomposition of data of one type to its subtypes. Both functions and data types may have particular attributes that describe them. For example, functions may be implemented with different techniques and data may be described in terms of their range of values.

The approach to be taken in developing a terminology for system description will be to perform these parallel decompositions generically, as much as possible, i.e., without reference to specific subsystem or implementation, except by example. In other work, this terminology can be used to describe the systems for comparison.

2.1.2.1 Canonic Function Structures

Structured analysis is a general term for a group of methodologies, some of which have been automated, that formalize the process of system description. When we conduct structured analysis, the process entails decomposition of both functions and data types. Functions (or sometimes entities) are represented by boxes or bubbles and the data that flow between them are represented by arcs. When a bubble is divided into smaller bubbles, new arcs are drawn between these bubbles, but also the arcs connected to other larger bubbles have to be divided into arcs to or from the smaller bubbles. Whether or not we use structured analysis tools, the following observation applies.

As functions are decomposed, we usually think of the objective functions (Cf. the hierarchy of objectives) as the primary functions. These provide the context and the basis of the analysis. As analysis proceeds, a pattern emerges that, among the subfunctions in each function, there are two special functions, control and communication, and often a category of lesser functions called support that must be included in order to make the job complete. This suggests a canonic structure for functional analysis; one that consists of these four function types: control, communications, objective functions, and support functions.

As noted above, objective functions are derived from the purpose of the system. Support functions contribute to the performance of the objective functions and become objective functions in their own right as decomposition continues. There is usually not a clear dividing line between the set of primary (objective) functions and the set of secondary (support) functions, except an arbitrary one.

Often, control and communication are treated as support functions, but since they have special roles in gluing the system together and enabling its behavior, they need to be viewed uniquely. This is exemplified in the special symbology afforded these functions in structured analysis.

There must be a control function. This special kind of function has a special symbol in structured analysis, the dotted circle. The role of this function is to activate or change the state of the other subfunctions within the domain of the function being decomposed. When a function is decomposed, one (and only one) control function must be defined to control the subfunctions. When a subfunction is decomposed, its internal control function should receive all control data from the external control function. Often, analyses are seen, where an external control line leads to a subfunction rather than to the internal control subfunction. This may cause control contention and should be avoided. On the other hand, delegated control may make this structure unavoidable.

There must also be a mechanism for communicating among the subfunctions. This applies both within the function and with subfunctions of other functions, since the data flow is being decomposed at the same time. This special function is symbolized uniquely as arcs instead of circles. The communication of control data that flows among control functions (and from control functions to other functions) is indicated in another special way, by dotted lines. On the other hand, communications are also often listed as a support function in a solid circle in order to make explicit the process of handling the data. These two views of communications are necessary but are also a source of confusion.

In the system analysis approach, control and communication functions will be stated explicitly in each list.

2.1.3 Resources

Resources are simply stated as all the physical elements of the system including people and equipment. System Functions are allocated to resources to achieve the objectives of operational

functions. Resources may be assigned to perform multiple functions. This will cause resource contention. The pathways for data flow among resources comprise the physical connectivity between resources and are also subject to contention.

C3 System Functions are allocated to C3 resources to support the decision making process. C3 equipment resources consist of the computational and communications assets used to control the activities of other resources. People are resources who participate in Operational and System Functions. Through the System Control function, they also affect Equipment Functions. In this general sense, there are C3 functions and resources at all levels of combat systems.

2.1.4 Organization

This is a very important structural aspect in the description of a system. It is through Organization that resources are applied to the accomplishment of the operational goal. It is also the least understood aspect in terms of how those effects are manifested.

As stated earlier, the activity of an organizational element can be represented by the sequence of decision process functions performed for its purpose. The outputs of these functions represent perceptions, decisions, and actions that affect the operation of the organization and influence other parts of the world, including the opposition, but also supporting organizations. The interaction with other organizational elements can be represented by a structure of flow between decision process functions.

The principal considerations in the Organization domain are the authority, responsibility, and access to information assigned or provided to the decision maker. These are important conditioning factors in whether a particular decision will be made, which, in turn, affects which activities and outcomes are produced as a result.

2.2 RELATIONSHIP OF CLASSES OF FUNCTIONS

These three classes of functions are, of course, part of the Hierarchy of Objectives. At the same time, they are decomposable within their own domains, that is, an operational function can be decomposed into operational subfunctions and a system function can consist of system subfunctions. Operational Functions are most closely associated with the purpose or goal being pursued, rather than with the system configuration or technique employed. System Functions are a set of procedures or tools at an intermediate level, which could be performed by various combinations of resources, people, and equipment, to accomplish the goal. Equipment Functions are an intrinsic characteristic of a particular type of equipment.

2.2.1 Operational Functions

As noted above, Operational Functions prescribe the primary purposes of the system and are derived from operational doctrine. Our source of motivation for the definition of Operational Functions is the set of Naval Warfare Publications (NWP) and the Top Level Warfare Requirement (TLWR) documents. Appendix A describes the philosophy and approach for identifying specific Operational Functions and provides a listing of them down to the Force level.

Operational Functions consist of the Hierarchy of Objective Functions for the primary Mission Areas and those that provide Mission Support. In addition, they include the Command Process Functions, which apply to all Mission Areas, not just the Command Mission Area, which overlaps them all.

2.2.1.1 Command Process Functions

A growing body of knowledge is being developed regarding the ability to understand the operation of military organizations in systematic terms. This is often referred to as "Theory of C3". It is based on various conceptual models of the decision process. It also addresses the sensing and response activities of an organization and its supporting systems. We have adopted elements of these concepts and adapted them for purposes of this effort. As a result, we have defined a generic set of functions called Command Process Functions. These are a special type of Operational Function and are described in detail in reference (c) and, in summary, in Appendix A.

Command Process Functions are important for system description in two ways. First, they form the basis for understanding and/or modeling the activity of single organizational elements. Furthermore, the interaction of the process functions of multiple organizational elements provides a representation of their organizational relationship. Second, they form the basis for defining System Functions for C3 Systems.

Associated with the achievement of an Objective Function is the need to perform the decision process functions that are inherent in any organization. For each organizational element, it must be possible to describe

(1) What information is needed and how it is obtained,
(2) How it is combined with other internal or external information,
(3) What situational inferences can be drawn about the information,
(4) What action is necessitated by the situation,
(5) How to carry out those actions, and
(6) How and when to modify items (1) through (5).

These six items are addressed by the principal Command Process Functions of Sense, Observe, Assess, Execute, Act, and Plan, respectively. All activity of an organizational element can be described using these terms in the context of the Objective (Mission) Functions being performed. These decision process functions are common to any organization. They form a set of functions that can be used as a uniform set of functions for describing organizational activity at all levels of command from Commander in Chief to sensor operator but also at all degrees of decomposition from coarse to fine.

2.2.2 System Functions

C3 System Functions are information processing and control operations performed by the Organizational element using some computer and communications resources to support the decision process functions that are being performed to support an Objective Function. C3 System Functions are described by specifying the decision process function, the organizational element performing the function, and the operational function involved. C3 System Functions are presented in detail in section 3.1.

2.2.3 Equipment Functions

An equipment function is an elemental or characteristic function of a piece of equipment. It is descriptive of that class of equipment in general. Some examples of equipment functions are given in Table 2-1. Equipment Functions will be of considerable importance at the end of the system analysis process when it overlaps with the system engineering process. The demands on equipment are the cumulative requirements of all system functions competing for the services of those equipments. C3 Equipment Functions are presented in section 3.2.

TABLE 2-1. EQUIPMENT FUNCTION EXAMPLES

EQUIPMENT	FUNCTION
Computer CPU	Process/Calculate
Computer Memory	Store/Retrieve
Computer Port	Input/Output
Computer CRT/Keyboard	Display/Entry
Transducer	Sense/Emit
Weapon Element(s)	Guide/Propel/Detonate
Radio	Transmit/Receive

SECTION 3.0 SYSTEM AND EQUIPMENT FUNCTIONS

This section presents an approach to defining C3 System Functions and their supporting Equipment Functions in such a way as to maintain a perspective on the dimensions of the problem. This approach will provide a means to define a complete view of the requirements and to avoid mixing names from different aspects of the problem as though they were in the same realm (tier) of function decomposition. This will be accomplished by defining C3 System Functions in terms of the decision process functions and also identifying the Mission Area and Organization Level involved.

3.1 RECOMMENDED SYSTEM FUNCTIONS

The C3 System Functions listed below are designed to relate directly to the Command Process Functions, but, because of common practice in C3 system design, the functions of Assess, Plan, and Execute have been grouped under a heading of Command Support. A list of C3 System Functions is found in Section 3.1.1, Discussion of C3 Functions. Figure 3-1 depicts the relationship of the C3 System Functions to the Command Process Functions. The overlap in Communications and C2 Functions reflects the way these two are inter-related. Table 3-1 lists the C3 System Functions in more detail.

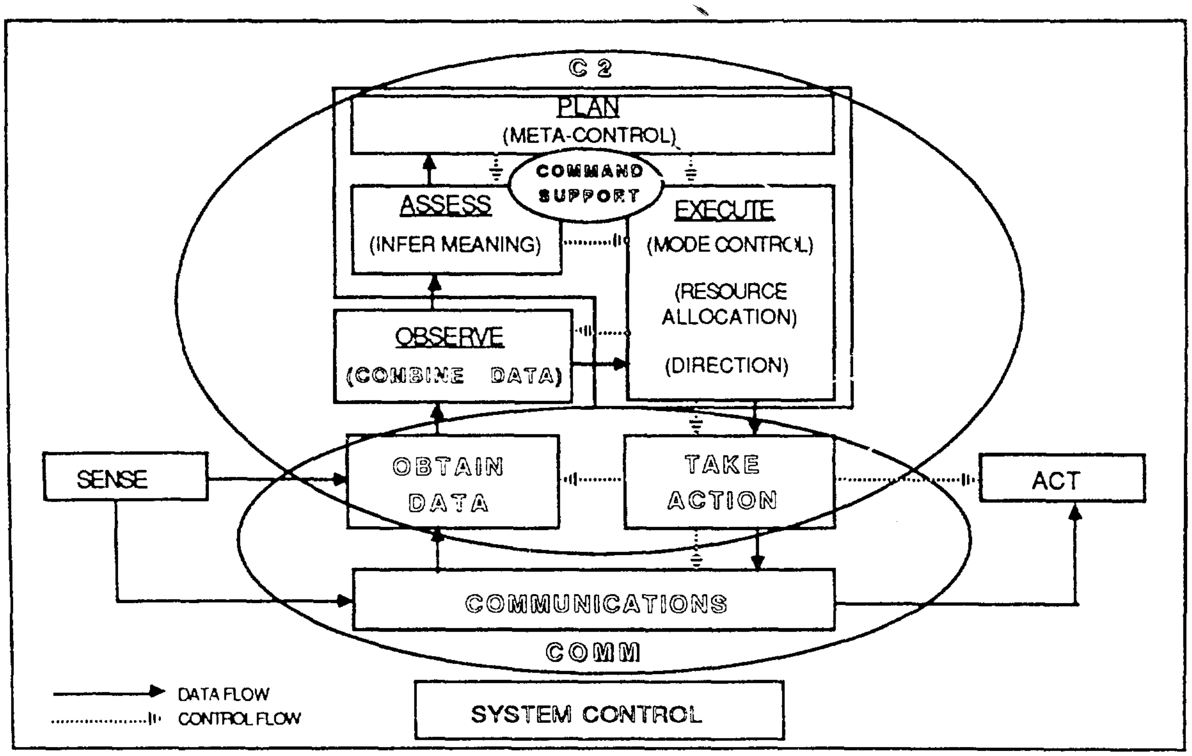

Figure 3-1. C3 System Functions Related to Command Process

The System Functions, when described in detail, may need to be put into context of Organizational level, such as Platform or Force, and in the context of Mission Area. Additional modifiers may be necessary if the function is dependent on situation or setting. For example, a function can be formed as "Integrate sonar data from the same platform" based on the System Function, "Similar Source Integration", the sensor/data type, "sonar", and the Organizational level, "Platform". The Mission Areas supported might be ASW, ASUW, or Intelligence, etc.

3.1.1 Discussion of C3 System Functions

The System Control function manages the relationship and configuration among the other system functions, establishes procedures for activation and interaction, and sets the priority for their accomplishment. For example, this function may set mode control and change function default values based on the situation or the operational function being performed.

The function, Obtain Data, is often called by the other names listed. It represents any manner of obtaining data, whether from sensory or message sources. Of course, message sources have some kind of sensory medium involved, as well. The list of data types obtained exemplifies the idea that data gathering is not necessarily Warfare Mission Area-specific, but often is Support Mission Area-specific.

The function, Combine Data, includes the classic Data Fusion idea, but also incorporates the integration of Force Readiness information and technical data bases. This function, too, is not Warfare Mission Area oriented by necessity, but as contacts become identified, the information may become of more value to WMA-specific functions. There are multiple levels of combining data (SSI, MSI and DSI) that may be invoked in different sequences depending on the nature of the data.

The group of Command Support functions address the Command Process Functions of Assess, Plan and Execute. All Mission Areas must have some kind of functions in this group. Tools for performing these functions, such as Prediction, are included. The idea of Coordination fits best here because it entails determining when and how to carry out procedures. This group produces the principal products of the Command process: direction and reports.

The function, Take Action, couples the direction and reports produced to the physical world. Equipment is activated and data submitted to internal or external communications.

The Communications function provides the interface and routing functions between C2 functions, which include all the other C3 System Functions.

TABLE 3-1. C3 SYSTEM FUNCTIONS

SYSTEM CONTROL
CHANGE/MAINTAIN ORGANIZATIONAL RESPONSIBILITY/STRUCTURE DESIGNATE/ASSIGN/ALLOCATE RESOURCES CONFIGURE/ENABLE PROCESSING AND DATA FLOW
Based on: Rules of Engagement Disposition & Posture of Forces Operating Procedures/Conditions

TABLE 3-1. C3 SYSTEM FUNCTIONS (Continued)

OBTAIN DATA (DATA ACQUISITION, DATA GATHERING, INFORMATION EXTRACTION, OBTAIN REPORT DATA)

Data obtained includes:
EW, Imagery, RADAR, and SONAR Sensory Data
SIGINT, IMINT, ACINT and external Intelligence Data
Non-Organic Surveillance Data
Navigation/Time (Grid, Reference) Data
Environmental/Oceanographic Data
Logistics and Readiness Data
Plans and Directives and Activity Reports

COMBINE (AGGREGATE) DATA

DATA FUSION (Includes Classification and Tracking)

SINGLE AND SIMILAR SENSOR/SOURCE INTEGRATION (SSI)
Inputs include measurements from:
EW, Imagery, RADAR, and SONAR Sensory Data
SIGINT, IMINT, ACINT and external Intelligence Data
Non-Organic Surveillance Data
Navigation/Time (Grid, Reference) Data (Own Ship/Force)
Environmental/Oceanographic Data

Outputs include:
SSI Tracks/Track Numbers
Identification/Classification
Own Ship/Force Position/Time Reference
Performance Prediction (Sensors/Weapons/Communications/Counters, etc.)

MULTI- AND DISSIMILAR SENSOR/SOURCE INTEGRATION (MSI/DSI)
Inputs include measurement and/or SSI data from:
EW, Imagery, RADAR, and SONAR Sensory Data
SIGINT, IMINT, ACINT and external Intelligence Data
Non-Organic Surveillance Data
Own Force Unit Positions from Navigation/Time Data

Outputs include:
Platform and Force Tracks/Track Numbers
Identification/Classification

FORCE EMPLOYMENT & READINESS STATUS

COMBINE OWN FORCE (PLATFORM) STATUS/PLANNED ACTIVITIES
Status Reports, Plans and Directives
Logistics and Readiness Data

INTELLIGENCE ESTIMATES OF ENEMY STATUS

MAINTAIN TECHNICAL/PRESET DATA BASE (RED/WHITE/BLUE)

TABLE 3-1. C3 SYSTEM FUNCTIONS (Continued)

COMMAND SUPPORT (COORDINATION, ASSESSMENT AND ALLOCATION)
Applies to all Warfare and Support Mission Areas.

- CAPABILITY ASSESSMENT (Own and Enemy)
- SITUATION ASSESSMENT (Achieving Own Objectives versus Enemy Intent)
- PLAN FORMULATION, EVALUATION AND GENERATION (Including Options)
- DEFINE/DESCRIBE TACTICS/PROCEDURES
- PREDICTION/SIMULATION (Support Assessment of Plans, Situations and Capabilities)
- COURSE-OF-ACTION SELECTION
- RESOURCE ALLOCATION/TASK-TARGET ASSIGNMENT
  - SPECTRUM MANAGEMENT
- DIRECTIVE/REPORT GENERATION

TAKE ACTION

- ISSUE DIRECTIVES
- ACTIVATE/CONTROL SENSORS/WEAPONS/PLATFORMS
- CONDUCT TRAINING
- MAINTAIN SUPPLIES AND EQUIPMENT

COMMUNICATIONS

- LINK/NET CONTROL
- OBTAIN DATA FROM C2 FUNCTIONS
- FORMATTING/PACKAGING DATA INTO MESSAGES
- TRANSMIT/RECEIVE MESSAGES
- ACCOUNTING/ROUTING (External/Internal, Outgoing/Incoming) MESSAGES
- PARSING/SORTING DATA FROM MESSAGES
- PASS DATA TO C2 FUNCTIONS

3.2 RECOMMENDED EQUIPMENT FUNCTIONS

The functions of a Command Information System, at the equipment level, consist of the computer functions of (1) equipment control, (2) data processing, (3) data transfer (input/output), (4) data storage/recall, and (5) data display/entry. Figure 3-2 depicts these functions and their interrelationships. Note that the control function, exercised through the operating system executive, interacts with all the other functions and that the last three are all seen as forms of input/output relative to the processing function. Items (1) and (3) represent control and communications, while (2) is the objective (purpose), and (4) and (5) are support functions. Additional support functions of power supply and cooling could also be considered. The C3 Equipment Functions are listed in Table 3-2.

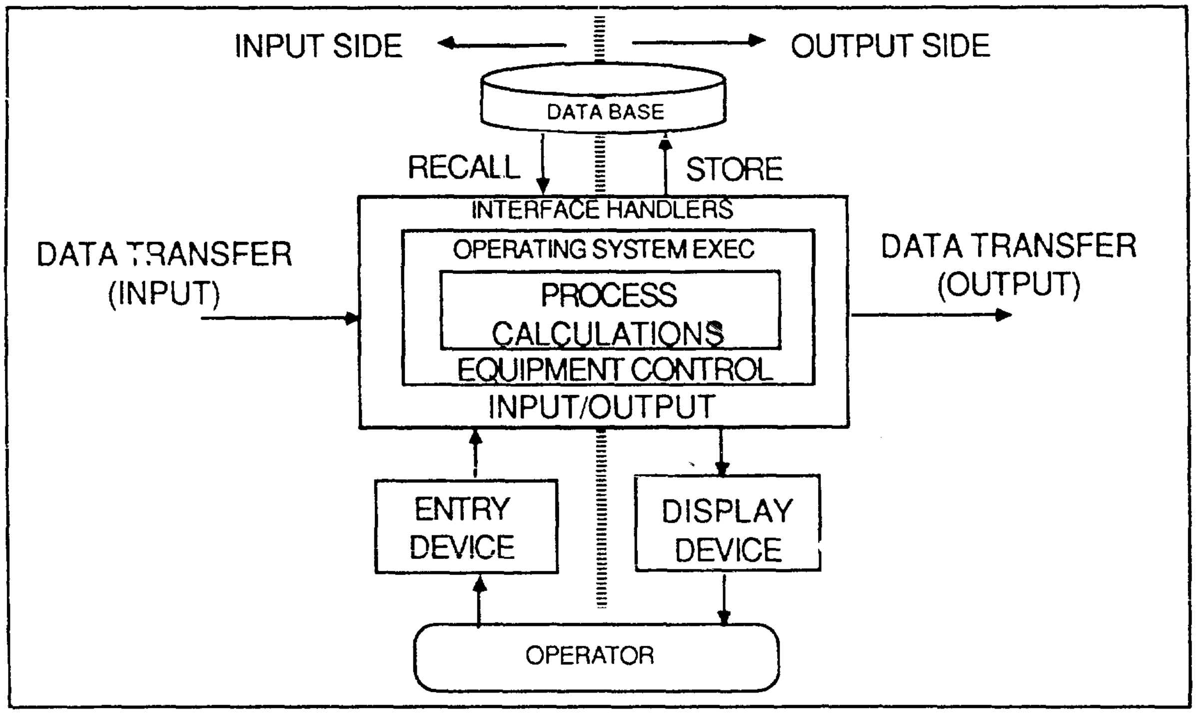

Figure 3-2. Generic Computer Equipment Functions

3.2.1 Discussion of C3 Equipment Functions

Equipment Control is affected by a combination of hardware and software actions, interpreted and actuated through the software operating environment, including the operating system and system executive programs.

Process (manipulate, calculate, transform) is any algorithmic sequence of operations on data, but, in particular, those that produce new data derived from the input data. The primary element is the central processing unit or a co-processor in the equipment.

Data Transfer (input/output) is the external interface function, with "external" being relative to the equipment under consideration, wherever that boundary has been specified or implied.

TABLE 3-2. C3 EQUIPMENT FUNCTIONS

EQUIPMENT CONTROL

CHANGE/MAINTAIN EQUIPMENT CONFIGURATION/PARAMETER SETTINGS

PROCESS DATA/CALCULATE

PRODUCE, FILTER, SANITIZE, CORRELATE, TRANSLATE, TRANSFORM
INTERPRET, EXTRACT, INTERPOLATE, EXTRAPOLATE
MULTIPLY, DIVIDE, ADD, SUBTRACT

DATA TRANSFER (INPUT/OUTPUT)

INTERFACE CONTROL
DATA EXCHANGE

DATA STORAGE/RECALL

CONSTRUCT/MAINTAIN FILES/DIRECTORIES
ENTER/EXTRACT DATA

DISPLAY/PRESENTATION/DATA ENTRY

DISPLAY DATA (BY CHARACTERISTIC)

Characteristics consist of:
Maps, Graphical Overlays/Boundaries
Tactical Symbology/Icons
Alphanumerics, Tables
Photographic Imagery
Radar/Sonar Video, Acoustic Intensity Grams/A-scans, ESM Signal Formats
Color, Brightness, Contrast

DISPLAY DATA (BY CATEGORY)

Categories consist of Warfare and Support Mission Areas, such as, CMD, AAW or Environmental Support.

ENTER DATA

By Keyboard, Pointing Device
See INPUT/OUTPUT for External Data Entry
See STORE/RECALL for Recalling Data Entry

PRODUCE HARDCOPY

Data Storage/Recall involves the memory write/read functions and the data base transactions and accounting. The data base management functions lay across the operating system and the store/recall function.

The Display/Entry function is where the human-machine interaction takes place. This includes the processes of formatting data for presentation and obtaining inputs from the data entry devices.

SECTION 4.0 INSIGHTS AND GUIDELINES

This section provides a collection of insights that are the result of analyzing functional descriptions from the perspective of the concepts derived in the course of developing this methodology. These insights suggest guidelines for how to examine or develop system descriptions.

4.1 PROCESS FUNCTIONS

Descriptions of systems often contain a function called "processing", such as "message processing" or "data processing". Since the terms "function" and "process" are synonymous, these function names do not convey specific meaning. It is recommended that the term process not be used to name functions except when it is meant to be generic or as used in the equipment functions, where it is, in fact, meant generically.

4.2 DATA HANDLING AND DISPLAY

The functions, Data Handling and Display, are also generic equipment functions. In fact, every system function handles data and any interactive system function must provide some form of presentation or display. This applies to all of the decision process functions. Data Handling and Display should not be on the same tier of decomposition as the functions they are supporting.

4.3 DECISION AIDING

In reference (c), it was noted that there are two kinds of decision: inferential and intentional. The former involves deciding what to believe; the latter concerns deciding what to do. These were related to the two sides of the decision process: monitor and control. This suggests that there are two kinds of decision aiding: one involved with interpreting data and the other with determining courses of action. In discussing systems, one often gets the sense that tactical decision aids are perceived as the latter type. In fact, any particular decision aid may have elements of both types. A data fusion decision aid will incorporate control functions for choosing ways to gather additional data to resolve ambiguities. An attack planning aid may include a test of data quality for a firing solution. Some decision aids are called Planning aids. These usually contain a combination of inferential and intentional methods of decision support.

4.4 CANONIC PARTS OF A DECISION

While decisions occur in all parts of the Command Process Model, there are always three parts of a decision: Formulation, Evaluation, and Selection. The Formulation step involves the generation of a set of hypotheses, in the case of an inferential decision, or a set of alternative courses of action, in the case of an intentional decision. These may be predetermined or created by the imagination of the decision maker. The Evaluation step involves assigning a qualitative or quantitative value to each hypothesis or alternative by some method. Selection is the act of deciding, i.e., making a choice, usually taking the option with the highest value.

Sometimes the Formulation of an hypothesis involves the association of two or more pieces of data. The Evaluation of that association may be to calculate a correlation factor based on classification parameters or tracker covariance. The Selection of the hypothesis from among others is often referred to as discrimination. In effect, any decision is a discrimination among hypotheses or alternatives. Detection, for example, is a discrimination between the "signal-plus-noise" and "noise only" hypotheses.

A by-product of the decision steps is an Estimation of some new parameters produced as a result of the Formulation and Evaluation. For example, target position is an estimate that results from associating two measurements, such as bearing and range or two bearings. If this hypothesis is chosen because the tracking variance produced by the Evaluation is small enough, the resultant position estimate is an inferred parameter. This discussion generalizes the relationship among the concepts of detection, association, correlation, tracking, estimation, classification, and discrimination.

On the intentional decision side, the Formulation step produces the characteristics (parameters) of the course of action such as sortie size, target assigned, and timing. The Evaluation predicts some expectation of success, and the Selection is made among the alternatives.

The generation of reports, plans, and directives involves documenting the estimated parameters and characteristics of hypotheses or alternatives produced during the decision analysis steps.

4.5 SYSTEM FUNCTION CATEGORIES

While the Command Process Model divides the process into two parts based on inference and intent, Command Information Systems tend to be divided with the Observe function separate from the combined functions of Assess, Plan, and Execute. The latter group are referred to as Command Support functions. This is a natural dividing line because the volume of data involved in the Observe function, consisting of data gathering, information extraction, and aggregation, is large and Observe provides the consolidated information for conducting the other set of functions. The display function is often shown as following or getting inputs from data fusion and leading to the Command Support group. Of course, the display function must also be capable of showing plans, assessments and ordered activities. But the division into these two categories is reasonable. A third category, communications, is also natural.

4.6 CLOSING THE SENSE-ACT LOOP

Models of the decision process usually show the input at the Sense function and the output at the Act function, and a path through the environment to close the loop. There is another closure usually omitted. That closure involves the effects on the Sense function caused by the actions to control sensors.

4.7 SURVEILLANCE AND INTELLIGENCE

Intelligence obtains data from non-organic sources via reports and it also piggy-backs on organic surveillance sensors. This makes it difficult to separate these Mission areas. But neither should Intelligence be too tightly bound to any one sensor type. This is often done with EW because the bulk of organic Intelligence is gathered from that source.

4.8 SURVEILLANCE FOR MULTI-WARFARE SUPPORT

Systems for AAW, ASUW, and ASW have historically been designed with dedicated sensors in mind. System function descriptions usually place those sensors under the auspices of their respective Warfare area. This need not be the case, and sensors should be considered a Multi-Warfare asset. In particular, sonar is associated with ASW, principally because it provides the predominant source of submarine information. It is also a good source of surface ship data. Passive sonar may soon be a better source of over-the-horizon information on ships than anything except airborne surface search radar.

On the other hand, there are sensor-effector control systems that need to have a quick response loop, such as ESM-ECM detector-deception loops. These loops need to be retained while treating the information gathered as an input to other processes, perhaps passed at a lower priority.

4.9 MULTI-LEVEL DATA FUSION

Multi-Sensor and Dissimilar Sensor Integration is usually performed at the track-to-track level after Single or Similar Sensor Integration has formed tracks. There are circumstances when measurement level association hypotheses should be formed between dissimilar sensors before making track decisions. This is especially true of passive sensors that do not derive a positional estimate as part of the measurement like active systems do.

4.10 REVERSE INFORMATION FLOW

The overall C3 system is usually viewed as providing information upward in the Surveillance organization and then downward (or forward), along with orders, to the tactical forces. There are, of course, orders also flowing downward on the surveillance side. There is also the view that information being gathered by the tactical forces may be useful to the surveillance system, not only at the fusion centers, but also at the sensor sites. Of course, this reverse flow may not be prudent under EMCON conditions and is lower priority to supporting engagement in hot conflict.

SECTION 5.0 C3 ASSESSMENT FACTORS

The objective of an assessment of proposed C3 systems is to decide on an investment strategy for procuring and developing those systems. This decision is dependent on proposed architectures for these systems, as well as on the capabilities of parts of the system. The question of choosing assessment factors involves identifying the characteristics of systems that represent capabilities and relating these to how well the overall force accomplishes its mission.

As defined earlier, the probability of the preferred outcomes, conditioned on the situation, is a general criterion of goodness to be applied. When this criterion is applied to two systems that perform the same function, it may be a simple matter of comparing their capabilities (probabilities) in similar situations and picking the one with the better performance. If one works better than the other in one situation and vice versa for another situation, then the importance of the situation or the need for both systems may become an issue. For example, a sonar that works well in deep water and one optimized for shallow water will result in a question of how to afford both or rely on existing assets for one or the other capability, since both situations are stated requirements. Finally, the difference in cost for options must be compared to the difference in value of the resultant outcomes weighted by the probabilities of the outcomes at the level of the objectives that are being served by the function that both systems perform.

On the other hand, when the criterion is applied to two systems that perform different functions, their capabilities cannot be directly compared. (In fact, the case of the two sonars above actually falls in this category, since detection in shallow or deep water may be considered different functions in a sense.) An approach to their comparison involves examining the "marginal" difference in the resultant outcomes at the higher level of objectives served by the two functions, with and without each system. This approach assumes that the probabilities of the outcomes can be calculated as discussed in reference (d). The marginal analysis is like taking a partial derivative of the probability of the higher level outcomes relative to the probability of performance of the function in question, and doing that for each function performed by a system under consideration. It is obvious that this results in answers that are dependent on the level of performance of the other systems, not just that of the one being examined. In general, the better the performance of the other systems, the more valuable is an improvement in the system under consideration, if they all depend on each other (the weak link principle). If there are complementary systems that do not depend on or support the lower level function being considered, but contribute to the higher level objectives, their performance reduces the value of improvements in the one being considered (effective alternatives).

In reference (d) and section 1.0 of this document, the idea of treating the probability of making decisions as a fundamental measure of how the element of Command influences mission outcomes was adopted. This probability was conditioned on the situation, so that the idea of "right" decisions is context dependent. Any assessment of C3 System Functions must address how the capabilities of the system to provide observation, assessment and course-of-action information affect, i.e., condition, the probability of making decisions, right or wrong. In addition, C3 functions were recognized to be an enabling condition on all functions. This suggests that the value of C3 systems is increased as capabilities in other systems is also improved. Conversely, ineffective C3 is more detrimental when the sensor and weapons systems are improved; witness the lack of effective C3 at the introduction of cruise missiles.

In summary, the probability of having the right information and giving the right direction must be at the heart of any measure of effectiveness or assessment criterion for C3, although the criterion may be stated in other terms. Measures concerning information should involve an understanding of the dispersion from the true state of the world. In assessing directive effectiveness, the likelihood of achieving objectives should be the basis.

5.1 HIERARCHY OF ASSESSMENT CRITERIA

Just as there are hierarchies of objectives for establishing functions and performance related to outcomes, there is a hierarchy of assessment criteria for examining system capabilities. These criteria are related to the classes of functions at the operational, system and equipment levels.

5.1.1 Operational Assessment Factors

Mission Success Criteria are the ultimate basis for comparison of alternative architectures, including the assumed tactics, procedures, organization and combat situation. The hierarchy of objectives establishes an interrelationship of performance in accomplishing these objectives. As discussed in references (c) and (d), the objective of the Command Decision Process is to maximize the probability of making decisions that result in achieving the mission objectives. These are the extrinsic objectives of Command. The principal intrinsic objective is coordination, which may be defined as achieving coherence of goals, plans, and actions. These are supported by a need for coherence of information about goals, plans and actions, as well as the information involving monitoring (observing and assessing) the situation and orders to execute other actions. C3 System assessment factors should be based on achieving this objective of coherence.

5.1.2 C3 System Assessment Factors

A C3 System consists of the people, equipment and functions arranged in organizations, connectivities and procedures to control the activities of the other components. The states of a C3 System consist not only of the physical states of the people and equipment, but also the information states representing knowledge and intentions. Information states will be the basis of C3 System assessment factors. Characteristics of the physical equipment will be addressed in Equipment assessment factors.

Five characteristics of information, often recognized as important aspects of information processing, appear to be closely related to the idea of coherence, mentioned above. These are completeness, accuracy, uncertainty, consistency, and timeliness. Within a C3 system, these can only be as good as the information provided as input, so there is a bound on how well the C3 system can make use of that information. Furthermore, these characteristics of information handling are not independent in their contribution to achieving the operational objectives. Trying to optimize one may require relaxing another. In particular, timeliness is usually seen as exchangeable for completeness, accuracy, and reduced uncertainty, that is, given more time, the others are more achievable. However, it is becoming more common to emphasize speed. This provides the decision maker with the most up-to-date information. In addition, since information is subject to decay with time, timeliness contributes to consistency of the information among multiple decision makers. What needs to be made clear, within the system, are the limitations of the completeness, accuracy, and uncertainty entailed by the information, so that the decision maker can take that into account. Uncertainty (or confidence) is often included in sensor and data fusion information, but it is rarely part of assessments, plans and directives. This suggests another level of assessment, concerning whether the system provides "accurate" estimates of the limitations of the information. With the emphasis on speed, there is also a need to prioritize information processing flow. The ability to correctly handle priorities is an important aspect of timeliness.

5.1.2.1 Completeness

Completeness is a comparison of the number of information elements of interest in the real world and the number in the system. Completeness has to be considered in relative terms. The test of completeness involves a judgment about the <u>relevance</u> of the information to the task at hand. The

idea of coverage involves not just the geographic envelope, but it also involves the context dimensions, such as mission area. Completeness also involves the concept of comprehensiveness. The underlined words are aspects of completeness.

The completeness of information available in a timely manner is different from the completeness of the minimum essential data that needs to be sent immediately. Less essential data may be sent later and still be timely, if it is needed for later analysis.

Completeness might also be applied to the area of viable courses of action. But, this is an open-ended statement since there is no way to state how many viable courses of action there are. The completeness of the directive that executes a course of action may be assessable.

5.1.2.2 Accuracy

Accuracy is a comparison of the value of an information element in the real world and the value estimated by the system. For continuous variables this is a difference error for each instance and an average error for the overall factor. If average error is not zero, this is a bias. The event distribution is a conditional probability of the estimate, given the true value. The error distribution may also be dependent (and therefore, conditional) on the true value or related parameter, e.g., weapon accuracy varies with range.

For discrete variables, like classification, individual outcomes are true-false and a percentage correct measure is more appropriate for the overall factor. A confusion matrix is a table of the percentages of inferred values versus true values. For each true value, the percentages must add to 100%, so this is a conditional "probability" matrix. The percentage correct is that percentage for the case when the inferred value matches the true value.

The continuous conditional distribution and the discrete conditional matrix are not completely analogous. In the continuous case there is no "percentage correct." Instead, the error is a measure of the "distance from correct."

The approach, whether for the continuous case or the discrete, can also be applied to the projected value, produced when predicting consequences of courses of action, versus the eventual true value. When applied to inferential decisions, accuracy refers to the difference between the true state of the world as it has evolved to the present time and the view being held. For intentional decisions, it refers to the true state of the world that will occur after the projected action is carried out versus what was expected to happen.

5.1.2.3 Uncertainty

Uncertainty is a measure of confidence in an estimated value. For continuous variables, the variance (average squared error), or the standard deviation (or multiples thereof), is often used as a measure of uncertainty. For discrete variables, these parameters are not well defined. The probability of being correct, as discussed in terms of accuracy, is also sometimes used as a measure of uncertainty as well. Dempster-Shafer theory, on the other hand, addresses a range of certainty from degree of belief to degree of plausibility. (Their complements are the degree of doubt and degree of disbelief, respectively.) When the difference in these two values is zero, there is full certainty about the strength of evidence, even if this evidence has a probability of being correct associated with it. (In fact, the difference is zero when these values are equal to each other by being equal to the probability of the evidence.) When the difference is one, there is total uncertainty.

Another measure of uncertainty is entropy. The measure of information for an event is the negative of the natural logarithm of the probability of the event, i.e., $h(x) = - \ln p(x)$. The entropy for the

distribution of all events is the expected value of the information, i.e., H(x) = S h(x)*p(x), for discrete distributions, and H(x) = ∫ h(x)*p(x) dx, for the continuous case. For a continuous distribution, the entropy is in the range of minus infinity to plus infinity, with $-\infty$ representing certainty. The difference in entropy for two gaussian distributions is equivalent to the ratio of their standard deviations. For discrete distributions, entropy is in the range of zero to plus infinity, with zero representing certainty. This occurs only when one event has probability one.

Increasing entropy represents a decay in information. Since entropy increases with time (assuming no energy, i.e., new information, is introduced), the role of timeliness can be related to the decay of information.

Conditional entropy provides a measure of how much information or uncertainty a process adds to previous knowledge. A deterministic process adds no information, although it may alter its representation. Taking measurements or receiving information may or may not reduce entropy depending on the reliability of the information.

5.1.2.4 Consistency

While completeness, accuracy and uncertainty are measures relative to the true state of the world, as represented by one information set, consistency is a measure of the similarity of the completeness, accuracy and uncertainty represented in two derived views of the state of the world. It can be measured by comparing the number of relevant information entities, their values and range of uncertainty of those values in two representations. Any lack of consistency between two views should make us question the completeness, accuracy or uncertainty of both. Forcing consistency may result in the loss of this possible diagnostic of error in the system. It is not good to be consistent, but wrong. Two systems with the same errors may be totally consistent, but that consistency is not a useful criterion unless those systems are first deemed accurate.

5.1.2.5 Timeliness

Timeliness is not synonymous with fast. Timeliness requires a balancing act with regard to speed versus completeness, accuracy, and uncertainty and also with regard to its effect on consistency. Premature action or reaction can have a deleterious effect on objectives, particularly in crisis situations or when the enemy may be practicing deception. On the other hand, delay can cause a decay in information. Conveying the degree of uncertainty in information can provide a hedge against over-reliance on it, while providing the information in a timely manner.

Reference (d) discussed the effect of timeliness of issuing and delivering directives in terms of its impact on the time remaining for the action to be carried out successfully and the probability of success implied by the time factor. Initiating action prematurely can also result in a reduction in probability of success. This effect comes not from the speed of issuing and delivering orders, but on the validity of the information and feasibility of the course of action when the information is in error. Once a decision has been made, timeliness is directly related to issuance and delivery time.

5.1.3 Equipment Assessment Factors

These factors are focussed on the hardware and software as tools to help perform the system functions that are assessed on the basis of the factors above. There is not a sharp delineation between these levels, since one level supports similar functions at the higher level. For example, interoperability of procedures is supported by interoperability of communications and consistency of processing algorithm results.

5.1.3.1 Capacity and Throughput

Often the default approach for assessing C3 systems is limited to determining throughput and capacity of communication channels or computer processes. This can be a function of the hardware involved or it could be a result of the efficiency of the software algorithms. In general these should be considered equipment assessment factors, except when a human is involved. Then the throughput questions become a system level issue.

Actually, throughput is a form of capacity, in terms of flow. Throughput can be stated in terms of rates, either average or instantaneous (including burst rate). Three kinds of capacity are involved: communications capacity or throughput, processing capacity or throughput, and storage capacity. Storage and retrieval rate may be another throughput factor, although it is a form of communication throughput (between the devices involved) or processing throughput, i.e., the storage or retrieval process.

At the higher level of system issues the question becomes whether the completeness, accuracy, uncertainty, consistency and timeliness of information is better in one system (or architecture) than in another. While it is natural to expect that more throughput and capacity is better, the question of what it costs must also be considered. But even more importantly, it is not necessarily the case that a higher likelihood of making a decision is the result of this greater capability. It may even be the case that the communication emissions give the enemy more information than is being gained. This may mitigate the advantage of making the decision if the enemy gets to make a better decision than they would make otherwise. This also addresses the issue of security of information, not just its content but also its detectability and volume.

It should be an objective of C2 system designers to determine the minimum amount of data needed to perform the decision process functions and support effective decision making. Conversely, it is the requirement on communications systems to make the most capacity available under prevailing environmental and jamming conditions, but this capacity need not be used.

5.1.3.2 Delay

Delay, for a particular item in the event stream, is the inverse of the throughput plus a waiting delay. While throughput is a function of the equipment, delay is a function of throughput and loading, the latter being a factor external to the equipment. Measures of throughput and delay should be conditioned on the loading. The fundamental measure of throughput is the probability that a number of events occur as a function of time. This is usually treated as a Poisson distribution. Different processes have different characteristic inter-event times represented by the parameter 1/l, so that the average rate is l. The parameter may depend on the nature of the input, so that there is a conditioning effect on the distribution based on the input.

This assessment factor can also be applied at the system or operational level, since the parameter is a representative characteristic of any process.

5.1.3.3 Interoperability

Interoperability is an expression of compatibility. It can be assessed at various levels. As is the case with most measures, it is more easily addressed toward the physical end of the spectrum than at the operational end. At the lower levels, it might be related to interconnectibility, including physical connectors, waveforms, protocols and cryptologic keys. At a higher level, it involves terminology and symbology, including characters, words and data structures. Above that, the questions of operational procedures and cultural differences become issues. It is not clear at what point this becomes a system assessment factor or an operational one.

5.1.3.4 Usability

Related to interoperability is usability. In a sense usability is a form of interoperability between the human and the equipment. The presentation of information can affect comprehensibility. Not only clutter and format issues need to be addressed; the way context and related information is put into juxtaposition can affect comprehensibility and recognition of significant events. Since conditioning is a form of context setting, knowledge about conditioning relationships can help determine which antecedent information should be made readily available or presented with the consequent information.

While, in the past, humans have had to adapt to the limitations of the machine, more sophisticated design is altering the balance. But even good operator machine interface designs may be different, so the lack of commonality of "look-and-feel," terminology and procedural sequence may require adjustment by the operator using different systems and different training requirements for each design.

5.1.3.5 Survivability

The survivability of the equipment may be less important than survivability of the information either as multiple copies in one platform or rapid reconstitutability from another platform. Large numbers of small, similar machines may be more survivable in a redundancy sense. Other measures of availability, including reliability and maintainability are part of survivability, perhaps under the different conditions of weapon impact and otherwise.

5.1.3.6 Security

This factor, in the context of equipment assessment, includes cryptologic coverability, emissions control (including leakage), and multi-level data handling guards. In addition, at higher levels, it includes personnel security, and, ultimately, cover and deception techniques.

SECTION 6.0 REFERENCES

a. Command, Control, Communications and Intelligence Operational Requirements Framework: Command Process Model, Naval Ocean Systems Center Technical Document (TD 1309), July 1988

b. Command Process Model, Naval Ocean Systems Center Technical Document (TD 1937), September 1990

c. Command and Control Systems Requirements Analysis: The Hierarchy of Objectives Approach, Naval Ocean Systems Center Technical Document (TD 1938 Vol 1), September 1990

d. Command and Control Systems Requirements Analysis: Measuring C2 Effectiveness with Decision Probability, Naval Ocean Systems Center Technical Document (TD 1938 Vol 2), September 1990

APPENDIX A OPERATIONAL FUNCTIONS

A.1 INTRODUCTION

This appendix provides a summary of the Operational Functions, including the Command Process Functions, which establish the purpose for performing System Functions. In addition, there are contextual settings and situations that also affect the conditions for conducting operations and that influence decision making. These factors are listed in Addendum 1 to this appendix.

A.2 OPERATIONAL FUNCTIONS

The Mission, Functions and Tasks of the Navy are summarized below. This list has been modified to add aspects of Naval Operations not listed in NWP-1.

(a) The Mission of the Navy (by act of Congress) is to "be prepared to conduct prompt and sustained combat operations at sea in support of U.S. national interests".

(b) The Functions of the Navy, for the purposes of this document, are Power Projection, Sea Control, Sea Lift, Strategic Deterrence, and Defense of the United States.

(c) The Tasks of the Navy fall into two groups; Fundamental (Primary) Warfare Tasks and Support Tasks.

(1) The former are often referred to as Warfare Mission Areas: Anti-Air Warfare (AAW); Anti-Submarine Warfare (ASW); Anti Surface Warfare (ASU or ASUW); Strike Warfare (STW); Amphibious Warfare (AMW); Mine Warfare (MIW) and Navy Special Warfare (NSW). The addition of Command (CMD) has been proposed in order to provide for the task of multiwarfare direction, control, and coordination (see comments about C3 below). Transport needs to be added to cover the Sea Lift Function.

(2) The tasks in the latter category are also known as Support Mission Areas and consist of: Ocean Surveillance; Electronic Warfare (EW); Command, Control, and Communications (C3); Intelligence (INT); Logistics (LOG). There is a proposed task that covers Oceanometry (Oceanography, Meteorology, Underwater Acoustics, Navigation and Time, and Cartography). Training is often included in Logistics, but may warrant a separate entry. Mobility, Fleet Support Operations, Non-combatant Operations and Construction are listed as functional areas in CINC requirements and readiness assessments and, therefore, have been included in the list.

The C3 task is listed under the Support Tasks and as such must be interpreted as the means of processing, storing, displaying, and disseminating information (especially Command information) rather than the Task of "Exercising Command", which appears to be the intent of a proposed Fundamental Warfare Task, Command.

Each of the twenty Tasks of the Navy is intended to be performed as the means to accomplish the Functions of the Navy.

A.3 HIERARCHY OF OBJECTIVES

The Hierarchy of Objectives shown in section 5.0 of Addendum is taken from reference (c). These functions are activities performed by combinations of Mission Area capabilities to accomplish the objectives of the Functions of the Navy.

A.4 OPERATIONAL SETTINGS

The Operational settings listed in section 6.0 of the Addendum provide additional conditions as context for performing functions and evaluating combat and decision making outcomes. The Force Type and Platform Type are influences because of the nature of their roles, by definition.

A.5 ORGANIZATION

Organization is another context setting consideration, but is listed separately in section 7.0 of the addendum, because of its specific relationship to decision making functions.

A.6 COMMAND PROCESS FUNCTIONS

The Command Process Functions complete the formulation of the Operational Functions and considerations. The summary provided in section 8.0 of the addendum is an excerpt from previous descriptions in references (c) and (d).

ADDENDUM 1 TO APPENDIX A
OPERATIONAL FUNCTIONS, SETTINGS, AND ROLES

1.0 NAVY MISSIONS

The Mission of the U.S. Navy, as set forth in Title 10, U.S. Code, is to be prepared to conduct prompt and sustained combat operations at sea in support of U.S. national interests; to assure continued maritime superiority for the United States.

2.0 FUNCTIONS OF THE NAVY

2.1 POWER PROJECTION

Power projection is a means of supporting land or air campaigns utilizing capabilities designed for naval tasks. Power projection covers a broad spectrum of offensive naval operations including strategic nuclear response by fleet ballistic missile forces, employment of carrier-based aircraft, amphibious assault forces, and naval bombardment with guns and missiles of enemy targets ashore in support of air or land campaigns.

2.2 SEA CONTROL

Sea control is the fundamental function of the U.S. Navy and connotes control of designated sea areas and the associated air space and underwater volume. It does not imply simultaneous control of all the earth's ocean area, but is a selective function exercised only when and where needed.

2.3 SEA LIFT

Sea Lift is the fundamental function of providing the means to carry military reinforcements and resupply from CONUS seaports of embarkation (SPOE) to seaports of debarkation (SPOD). This function also includes providing protection for the cargo and personnel carriers and keeping Sea Lines of Communication (SLOC) safely navigable. The escort forces which provide organic protection are a subset of the SLOC Protection Forces.

2.4 STRATEGIC DETERRENCE

This function does not necessarily project power, thus it is clearly not Sea Control or Sea Lift and it only implicitly defends the United States. Strategic Deterrence is the preparedness to project power to prevent the enemy from launching nuclear (or even conventional) strikes against the United States or its Allies.

2.5 DEFENSE OF UNITED STATES

There has always been a Naval role in defending the country. This role is explicit in recent programs, such as the Air Defense Initiative. This Function of the Navy involves Indications and Warning, Alerting land-based defense systems if weapons are launched, and Attacking enemy launch platforms before or after launch.

3.0 FUNDAMENTAL WARFARE TASKS

3.1 COMMAND

Command is the control function within the fundamental warfare task set. C3 Support (section 4.3 below) provides the communication and computation functions. Command is a unique function; it is usually not included in this list, because it is taken for granted, yet it is the most important one. It also is unique in that it is the penultimate human function and includes the intangible features of leadership and motivation.

3.2 ANTIAIR WARFARE (AAW)

The destruction of enemy air platforms and airborne weapons, whether launched from air, surface, subsurface, or land platforms. It comprises all the measures that are employed in achieving air superiority.

3.3 ANTISUBMARINE WARFARE (ASW)

The destruction or neutralization of enemy submarines. The aim of antisubmarine warfare is to deny the enemy the effective use of their submarines.

3.4 ANTI-SURFACE SHIP WARFARE (ASUW)

The destruction or neutralization of enemy surface combatants and merchant ships. Its aim is to deny the enemy the effective use of their surface warships and cargo carrying capacity.

3.5 STRIKE WARFARE (STW)

The destruction or neutralization of enemy targets ashore through the use of conventional or nuclear weapons. This includes, but is not limited to, targets assigned to strategic nuclear forces, building yards, and operating bases from which an enemy is capable of conducting or supporting air, surface, or subsurface operations against U.S. or allied forces.

3.6 MINE WARFARE (MIW)

The use of mines and mine countermeasures. It consists of the control or denial of sea or harbor areas through the laying of minefields and countering enemy mine warfare through the destruction or neutralization of hostile minefields.

3.7 AMPHIBIOUS WARFARE (AMW)

Attacks, launched from the sea by naval forces and by landing forces embarked in ships or craft, designed to achieve a landing on a hostile shore. It includes fire support of troops in contact with enemy forces through the use of close air support or shore bombardment.

3.8 SPECIAL OPERATIONS (NSW)

Naval operations generally accepted as being non-conventional in nature, in many cases clandestine in character. Special warfare, which often accomplishes fundamental warfare tasks, includes special mobile operations, unconventional warfare, coastal and river interdiction, beach and coastal reconnaissance, and certain tactical intelligence operations.

3.9 TRANSPORT

The actual provision of cargo and personnel transportations services, the operation of port facilities and the coordination of loading and shipment.

4.0 SUPPORTING WARFARE TASKS

4.1 OCEAN SURVEILLANCE

Ocean surveillance is the systematic optical, electromagnetic, and acoustic observation of ocean areas to detect, locate, and classify selected high interest aerospace, surface, and subsurface targets and provide this information to users in a timely manner. A target may be any hostile, neutral, or friendly platform or interest. Ocean surveillance provides the current operational setting in which Navy commanders deploy forces to do battle. Ocean surveillance is supportive of and dependent on C3 and intelligence, and therefore must be integrated with both. Organic surveillance should be included.

4.2 ELECTRONIC WARFARE (EW)

The electronic sensing and emissions (other than communications and radar) that provide surveillance, deception, and denial support for all warfare tasks. Its primary objective is to ensure the effective use of the electromagnetic spectrum by friendly forces while determining, exploiting, reducing, or denying its use by an enemy. Electronic warfare assists in the detection (a surveillance function) and targeting (a control function) of hostile forces, while making it more difficult for the enemy to detect and target friendly forces (a special purpose function). (It could be expanded to Spectrum Warfare by including Acoustic Warfare.)

4.3 COMMAND, CONTROL, AND COMMUNICATIONS (SUPPORT)

The communications and computational capabilities that provide decision making support for all warfare and other support tasks. Its primary objective is to ensure that the National Command Authorities, unified commanders, naval component commanders, and subordinate naval commanders are able to discharge their individual responsibilities by receiving sufficient, accurate, and timely information on which to base their decisions, processing to interpret the information and weigh alternative courses of action, and by having available the means to communicate these decisions to the forces involved. The same functionality applies for providing support to platform commanders and crew.

4.4 INTELLIGENCE (INT)

Intelligence is the assessment and management of information obtained via surveillance, reconnaissance and other means to produce timely indications and warning, location, identification, intentions, technical capabilities, and tactics of potential enemies and other countries of interest.

4.5 LOGISTICS (LOG)

The resupply of combat consumables to combatant forces in the theater of operations. A principal aim of naval logistics is to make the operating forces as independent as possible of overseas bases.

4.6 OCEANOMETRY

This term has been coined to combine a number of support areas, including Oceanography, Meteorology. Underwater Acoustics, Navigation and Time, and Cartography, all of which have something to do with making measurements in, on, and over the ocean.

4.7 TRAINING

This Mission Area covers schools and exercises. For the purposes of examining System Functions, the focus also concerns on-line simulation.

4.8 MOBILITY (MOB)

The entire Hull, Mechanical, and Electrical support capabilities are included, but speed, maneuverability, and endurance are principal factors.

4.9 FLEET SUPPORT OPERATIONS (FSO)

While this covers a number of activities, principal operations are replenishment at sea and acting as the enemy or targets for combat exercises.

4.10 NON-COMBATANT OPERATIONS (NCO)

This area includes Search and Rescue, Research, and Salvage operations

4.11 CONSTRUCTION (CON)

Primarily, the construction of shore facilities, including ports and airstrips, but this can also include deep sea construction.

5.0 HIERARCHY OF OBJECTIVES

The Hierarchy of Objectives is a set of functions that intertwine with the Missions, Functions, and Tasks of the Navy. They are most easily presented as a figure showing how various functions support other functions.

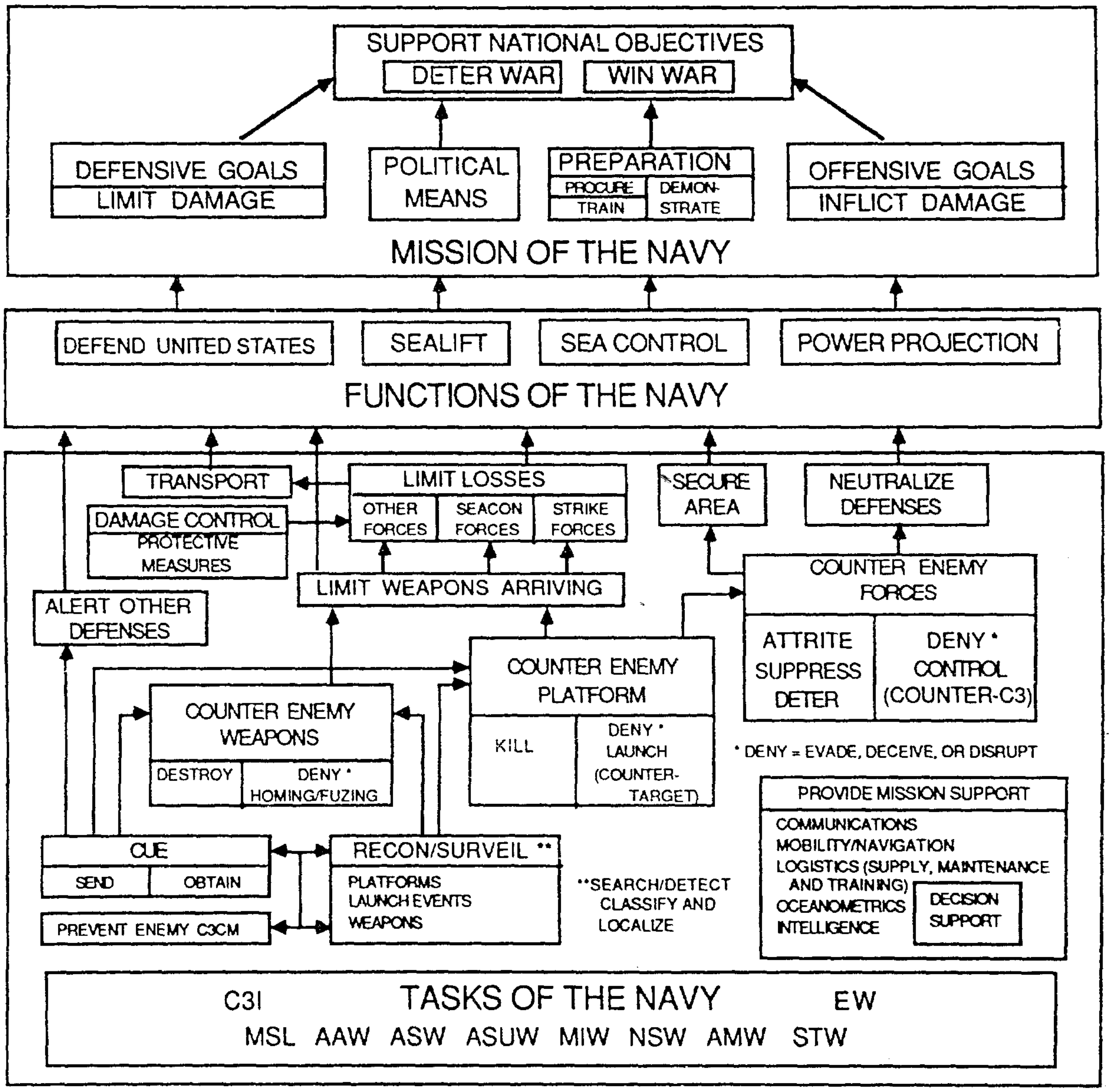

Figure A-1. Hierarchy of Warfare Objectives

6.0 OPERATIONAL SETTINGS

6.1 GEOGRAPHIC AREA

THEATER, REGION, SECTOR, ZONE
POLITICAL, TACTICAL, TOPOLOGICAL, GEOPHYSICAL

6.2 LEVEL OF CONFLICT

PEACE, CRISIS, LIMITED OBJECTIVE, GLOBAL
CONVENTIONAL, NUCLEAR, BIOLOGICAL, CHEMICAL

6.3 PHASE OF OPERATIONS

GENERAL OR MISSION-SPECIFIC PREPARATION
TRANSIT OR POSTURING
ENGAGEMENT (Counter-weapon, Counter-platform)
DISENGAGEMENT
RECONSTITUTION

6.4 FORCE TYPE

BATTLE FORCE/GROUP, AMPHIBIOUS TASK FORCE
UNDERWAY REPLENISHMENT GROUP, ESCORT FORCE
COASTAL AND MINE FORCE
SHORE ACTIVITY
SPACE FLEET

6.5 PLATFORM TYPE

SURFACE SHIP, SUBMARINE, AIRCRAFT, SHORE SITE, SPACECRAFT

7.0 COMMAND ORGANIZATION

This section is a listing of Organization Roles from the Commander of a Unified or Specified Command (i.e., Commander-in-Chief, Atlantic) level to the platform or site system operator level (e.g., sonar operator).

COMMANDER OF UNIFIED/SPECIFIED COMMAND

FLEET COMMANDER IN CHIEF

NUMBERED FLEET COMMANDER

TASK FORCE COMMANDER
(OPTIONAL: OFFICER-IN-TACTICAL COMMAND (OTC) OR
COMPOSITE WARFARE COMMANDER (CWC))

TASK GROUP COMMANDER (NORMAL: OTC/CWC)

TASK UNIT COMMANDER (WARFARE COMMANDERS)

WARFARE SUPPORT COORDINATORS (EW, SURVEILLANCE, INTEL, etc.)

TASK ELEMENT COMMANDER (OPTIONAL: SAU ETC.)

UNIT COMMANDING OFFICER

TACTICAL ACTION OFFICER (TAO)

WARFARE COORDINATOR/EVALUATOR

COMMUNICATIONS SUPERVISOR/OPERATOR

SENSOR SUPERVISOR/OPERATOR

FIRE CONTROL OFFICER/PETTY OFFICER

WEAPON LAUNCHER CAPTAIN/OPERATOR

AIR CONTROLLER

8.0 COMMAND PROCESS FUNCTIONS

The Command Functions consist of four major functions: Plan, Observe, Assess, and Execute, sometimes abbreviated as POA&E. Additional functions of Sense and Act may be appended to the list to couple the other four to the physical world. The functions of Receive and Issue (or Send) play a similar role in coupling to other decision-making activity.

8.1 OBSERVE

The Observe function combines information, which was Received or Sensed, for use by other functions. This is an all-encompassing "data fusion" function. It involves not only storing data together, but also association, correlation, and tracking functions and compilations of Intelligence data and Force status information. This aggregate of information is often referred to as the Tactical Picture at the combat level.

8.2 ASSESS

The Assess function makes use of the combined data to infer meaning about the situation, including enemy intent and potential outcomes of unfolding events. This is the real product of Situation Assessment, not just the Tactical Picture produced by Observe. The assessment determines whether mission objectives are being achieved, whether a new or revised set of plans is required or if a change of procedure under current plans is appropriate. If planning is required, the Plan function is invoked. If a change in procedure is suggested by the situation, the Execute function is notified and can change modes. Otherwise, Execution proceeds under the current mode, using information from Observe.

8.3 PLAN

The Plan function generates optional courses of action intended to achieve the mission. Based on the same kind of assessment that the Assess function produces about projected mission achievement, the Plan function evaluates and selects primary and contingency courses of action, including organizational responsibility, procedures and allocation of resources to general task areas. The criteria for assessing situations and changing procedures are defined by Plan for use in Assess in determining when these conditions exist. The procedures, including rules for allocating resources, are used by Execute to implement the plan and control its progress.

8.4 EXECUTE

The Execute function selects a specific course of action, based on the current assessment of the situation (from Assess). Using procedures established in the plan and data from Observe, specific allocation of resources and tasks or even specific guidance variables are generated as directives and Issued as orders or implemented as Actions. It is the Resource Allocation Directive that represents the product (outcome) of the decision-making process.

8.5 RECEIVE

Data are received from other information processing functions. This function is paired with the Issue function that sends the data.

8.6 ISSUE

Reports and Directives are Issued to other information processing functions. This function may feed many Receive functions.

8.7 SENSE

This function translates physical phenomena into information symbols.

8.8 ACT

This function translates information (control) symbols into physical phenomena.

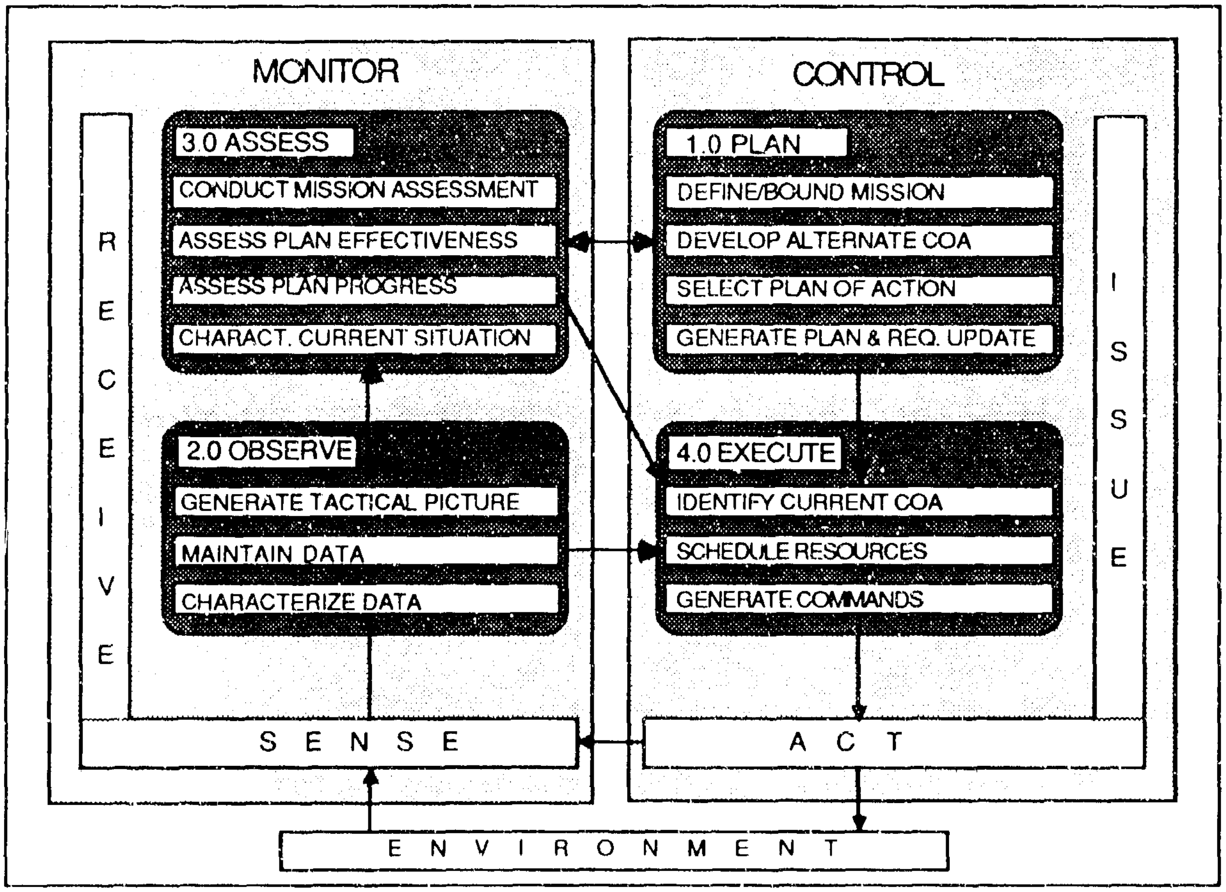

Figure A-2. Command Process Model

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